737 Classic Fuselage Skins

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Commercial airplane structure prior to FAA Amendment 25-45 was certified under the design requirement known as 'fail-safe'. Fail-safe structure provides the ability to fly and land safely with significantly large structural damage. Fail-safe design features provide protection against unanticipated, inadvertent damage and maintenance errors that airplanes may encounter in their service life. Fail-safe designs provide inherent robustness in the event of significant structural damage from several possible sources. Sources include fatigue damage, environmental deterioration (corrosion), accidental damage, maintenance errors, manufacturing flaws, and discrete events such as engine burst and impact damage.

Experience has shown that fail-safe design produces structure with a credible safety record. Numerous in-service incidents have demonstrated the ability of Boeing airplanes to fly and land safely with significant structural damage. Fail-safe design provides multiple load paths and damage containment. Generic fail-safe features can be summarized into the following categories:

- Alternate/intermediate/adjacent members that pick up load from failed members
- Fastener capability matched to load redistribution requirements
- Damage containment features, such as fuselage tear straps
- Boundaries of components and subcomponents, such as major joints or heavy frames
- Appropriate operating stress levels
- Material toughness and elongation characteristics

The specific requirements of 14 CFR Part 25, Section 25.571, Amendment 25-0 addressing fail-safe strength states the following: "It must be shown by analysis, tests, or both, that catastrophic failure or excessive deformation, that could adversely affect the flight characteristics of the airplane, are not probable after fatigue or obvious partial failure of a single principal structural element. After these types of failure of a single principal structural element, the remaining structure must be able to withstand static loads corresponding to…"

All fuselage primary flight-loaded structure must be designed to be fail-safe, that is, with sufficient residual strength to carry limit load with failure or partial failure of a principal structural element. This requires that the structure have multiple elements and/or redundant load paths and have adequate damage containment capability for a period of unrepaired use. Limit load conditions must consider tension, compression, shear, internal pressure, combinations of these loads, and, if appropriate, the presence of an active crack, in determining the residual strength.

Fail-safe design concepts should provide for visual damage detection by minimizing hidden critical details. Directed inspections are not considered within the scope of fail safety but are commonly applied to fail-safe structure in situations where fatigue or corrosion have been documented to occur either in-service or in test.

Fail safety has traditionally been achieved by providing multiple load paths and damage containment features with built-up structure. Multiple load path structure is defined as "redundant structure in which (with the failure of individual members) the applied loads would be safely redistributed to other load carrying members." In addition to the inherent load redistribution capability, built-up structure has other benefits related to fail safety:

- Multiple levels of fail safety are provided by allowing intermediate failures before reaching the maximum assumed fail safe damage size.
- A high level of resistance to unanticipated damage sources is provided by having separate members. If damage is initiated in one member, there is typically a significant period of unrepaired use before similar damage is initiated in adjacent members.
- Separate parts and mechanical joints provide boundaries for crack growth, tending to contain a crack in one member for a period of time before damage progresses to an adjacent member.
- Fail-safe capability for adjacent members typically provides significant static margin for non-failed conditions and maintains appropriate stress levels for operating loads.

Damage containment occurs when damage growth is interrupted by encountering an external or internal boundary, or by encountering a reduced stress field which significantly discourages further growth. Included under damage containment is the concept of crack arrest, defined as the "arrest of dynamically extending cracks within a continuous medium". Crack arrest features ensure that unstable rapid crack propagation at any load level up to limit load will be stopped within a continuous area of the structure prior to exceeding the maximum allowable damage.

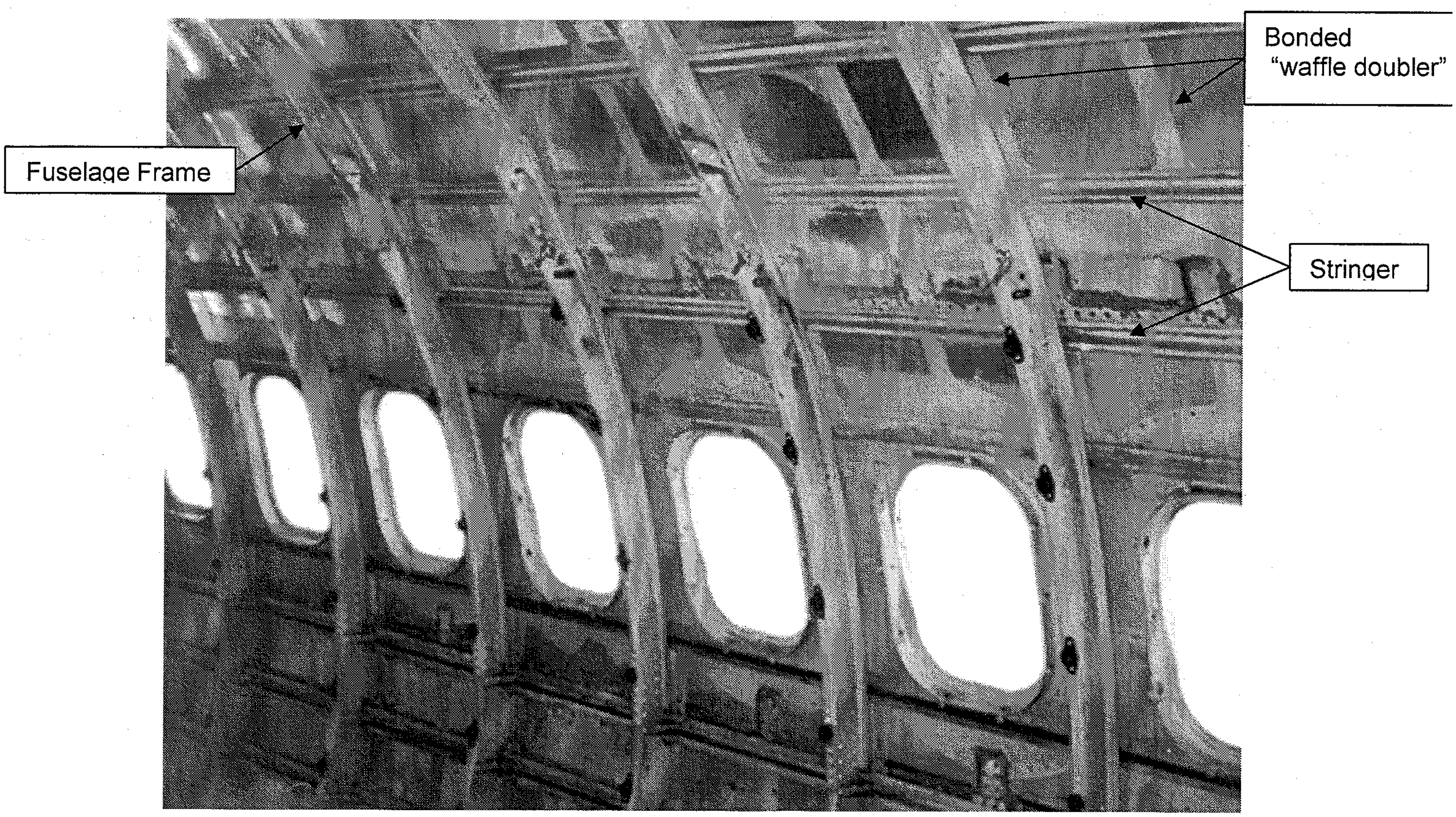
Fail-safe design as found in 737Classic Fuselage Skin assemblies

The 737 Classic fuselage is designed to be fail-safe through the use of three separate load paths. Two of the load paths are contained in the skin assembly itself. These load paths are created by structurally bonding two independent layers of material together, the external skin and the internal bonded doubler. Typically, both the skin and doubler are .036 inch thick 2024 aluminum alloy. Fatigue and damage tolerance testing, and in-service experience have clearly demonstrated that this design is effective in containing typical damage and allowing continued safe flight until the damage is detected. This design is effective because when damage occurs in the primary layer (external skin) due to fatigue, corrosion or other causes; the fail-safe internal bonded doubler provides an alternate load path. In this situation, the fail-safe bonded doubler does two things: first it provides an alternate load path for the loads to redistribute load around the damage: and second, it impedes the growth of the damage, containing it to a safe size until the damage can be discovered and repaired.

The third load path in the fail-safe design of the 737 fuselage is through the frames and stringers. Under normal conditions the frames and stringers share a portion of the load with the skins. When the skin is damaged, the frames and stringers are designed to allow some off-loading from the skin to occur to help redistribute the loads around the skin failure.

Fail-safety and Chem-mill Cracks

The bonded doubler, discussed above, is commonly referred to as a 'waffle doubler' due to its waffle-like pattern (see photo). This waffle pattern is achieved through a process known as "chemical milling" which chemically removes selected areas of the internal bonded doubler. This design feature is one of the critical advancements in aircraft design that allowed the 737 to become one of the most weight-efficient commercial airplanes ever developed. Below is a photograph of an airplane in heavy maintenance, and the skin assembly is clearly visible with the waffle doubler obviously seen between frames.



Though proving to be a dramatic weight savings while at the same time providing all of the fail-safe design features described above, this innovation in skin panel design resulted in a common fatigue detail that did not become evident until large numbers of 737 Classic airplanes had been in service for many years. This phenomena is commonly referred to as "chem-mill step cracking" as detailed in Service Bulletin 737-53A1210. Based on fleet data and fatigue testing, this type of fatigue crack is very well understood and its behavior can be predicted with high confidence. The fundamental fail-safe design philosophy has proven to be an effective way of safely containing this type of crack. For chem.-mill cracking of the external skin, the frames and internal bonded doubler successfully provide all of the fail-safe features intended. The internal bonded doubler and frames safely redistribute loads around the chem-mill crack in the skin, and the waffle pattern of the internal doubler provides physical boundaries that inhibit fatigue crack growth and contains cracks to a size that allows for continued safe operation of the airplane until the cracks are discovered by directed inspections.

Issues unique to the 1988 decompression accident

The configuration of the airplane involved in the decompression accident of 1988 was unique to the first 291 737-100/-200 airplanes ever produced. That early production configuration included a 'cold bonded' lap joint design that was phased out after in-service experience demonstrated several drawbacks. The room temperature cure adhesive used in this configuration was very difficult to assemble and commonly disbonded early in the life of these airplanes. This disbonded condition, if left unrepaired, frequently resulted in two unrelated conditions. Early fatigue cracks at the upper row of lap joint fasteners were found to occur due to high stress levels at the edge of each hole. Secondly, when left unchecked, moisture ingression into the disbonded lap joints occurred and corrosion commonly resulted. When working in combination, durability of these lap joints was difficult to predict and consequently, Boeing issued a Service Bulletin in 1972 that recommended inspections and eventually modification of this lap joint configuration. In the case of the subject accident airplane, a sudden uncontrolled decompression resulted due to the interaction of many small fatigue cracks and large areas of unrepaired corrosion.

This condition fundamentally does not occur with any 737 airplanes produced after Line Number 291, and in fact, none of those airplanes registered in the United States are in revenue service today.